

**PATENT APPLICATION**  
**FOR**  
**COMPOSITIONS AND METHODS INVOLVING**  
**DIRECT WRITE OPTICAL LITHOGRAPHY**

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9 **COMPOSITIONS AND METHODS INVOLVING DIRECT WRITE**  
10 **OPTICAL LITHOGRAPHY**  
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12 This application relates to provisional application Ser. No. 60/087,333 filed  
13 May 29, 1998 which is hereby incorporated by reference in its entirety.

14 **BACKGROUND OF THE INVENTION**

15 Technical Field of the Invention

16 This invention relates to optical lithography and more particularly to direct  
17 write optical lithography.

18 Description of the Related Art

19 Polymer arrays, such as the GeneChip® probe array (Affymetrix, Inc., Santa Clara,  
20 CA), can be synthesized using light-directed methods described, for example, in U.S. Patent  
21 Nos. 5,143,854; 5,424,186; 5,510,270; 5,800,992; 5,445,934; 5,744,305; 5,384,261 and  
22 5,677,195 and PCT published application no. WO 95/11995, which are hereby incorporated  
23 by reference in their entireties. As an example, light-directed synthesis of oligonucleotides  
24 employs 5'-protected nucleosidephosphoramidite "building blocks." The 5'-protecting groups  
25 may be either photolabile or acid-labile. A plurality of polymer sequences in predefined  
26 regions are synthesized by repeated cycles of deprotection (selective removal of the protective  
27 group) and coupling. Coupling (i.e., nucleotide or monomer addition) occurs only at sites  
28 that have been deprotected. Three methods of light-directed synthesis are: use of photolabile

1 protecting groups and direct photodeprotection (DPD); use of acid-labile 4,4'-dimethoxytrityl  
2 (DMT) protecting groups and a photoresist; use of DMT protecting groups and a polymer  
3 film that contains a photoacid generator (PAG).

4       These methods have many process steps similar to those used in  
5 semiconductor integrated circuit manufacturing. These methods also often involve  
6 the use of photomasks (masks) that have a predefined image pattern which permits the  
7 light used for synthesis of the polymer arrays to reach certain regions of a substrate  
8 but not others. The substrate can be non-porous, rigid, semi-rigid, etc. It can be  
9 formed into a well, a trench, a flat surface, etc. The substrate can include solids, such  
10 as siliceous substances such as silicon, glass, fused silica, quartz, and other solids such  
11 as plastics and polymers, such as polyacrylamide, polystyrene, polycarbonate, etc.  
12 Typically, the solid substrate is called a wafer from which individual chips are made  
13 (See the U.S. patents above which are incorporated herein by reference). As such, the  
14 pattern formed on the mask is projected onto the wafer to define which portions of the  
15 wafer are to be deprotected and which regions remain protected. See, for example,  
16 U.S. Patent Nos. 5,593,839 and 5,571,639 which are hereby incorporated by reference  
17 in their entireties.

18       The lithographic or photochemical steps in the synthesis of nucleic acid arrays  
19 may be performed by contact printing or proximity printing using photomasks. For  
20 example, an emulsion or chrome-on-glass mask is placed in contact with the wafer, or  
21 nearly in contact with the wafer, and the wafer is illuminated through the mask by  
22 light having an appropriate wavelength. However, masks can be costly to make and  
23 use and are capable of being damaged or lost.

1           In many cases a different mask having a particular predetermined image  
2 pattern is used for each separate photomasking step, and synthesis of a wafer  
3 containing many chips requires a plurality of photomasking steps with different image  
4 patterns. For example, synthesis of an array of 20mers typically requires  
5 approximately seventy photolithographic steps and related unique photomasks. So,  
6 using present photolithographic systems and methods, a plurality of different image  
7 pattern masks must be pre-generated and changed in the photolithographic system at  
8 each photomasking step. This plurality of different pattern masks adds lead time to  
9 the process and complexity and inefficiency to the photolithographic system and  
10 method. Further, contact printing using a mask can cause defects on the wafer so that  
11 some of the reaction sites are rendered defective. Thus, a photolithographic system  
12 and method that does not require such masks and obviates such difficulties would be  
13 generally useful in providing a more efficient and simplified lithographic process.

14  
15 SUMMARY OF THE INVENTION

16           In view of the above, one advantage of the invention is providing an improved  
17 and simplified system and method for optical lithography.

18           Another advantage of the present invention is providing an optical lithography  
19 system and method that dynamically generates an image using a computer and  
20 reconfigurable light modulator.

21           A further advantage of the present invention is providing an optical  
22 lithography system and method that does not use photomasks.

1           A still further advantage of the present invention is providing an optical  
2 lithography system and method that uses computer generated electronic control  
3 signals and a spatial light modulator, without any photomask, to project a  
4 predetermined light pattern onto a surface of a substrate for the purposes of  
5 deprotecting various areas of a polymer array.

6           According to one aspect of the invention, polymer array synthesis is performed using  
7 a system without photomasks.

8           According to a second aspect of the invention, polymer array synthesis is performed  
9 using a system with a transmissive spatial light modulator and without a lens and photomask.

10          According to another aspect of the invention, a Direct Write System transmits image  
11 patterns to be formed on the surface of a substrate (e.g., a wafer). The image patterns are  
12 stored in a computer. The Direct Write System projects light patterns generated from the  
13 image patterns onto a surface of the substrate for light-directed polymer synthesis (e.g.,  
14 oligonucleotide). The light patterns are generated by a spatial light modulator controlled by a  
15 computer, rather than being defined by a pattern on a photomask. Thus, in the Direct Write  
16 System each pixel is illuminated with an optical beam of suitable intensity and the imaging  
17 (printing) of an individual feature on a substrate is determined dynamically by computer  
18 control.

19          According to a further aspect of the invention, polymer array synthesis is  
20 accomplished using a class of devices known as spatial light modulators to define the image  
21 pattern of the polymer array to be deprotected.

1           An even further aspect of the present invention provides methods for synthesizing  
2   polymer arrays using spatial light modulators and the polymer arrays synthesized using the  
3   methods taught herein.

4           As can be appreciated by one skilled in the art, the invention is relevant to optical  
5   lithography in general, and more specifically to optical lithography for polymer array  
6   synthesis using photolithographic processes. However, it is inherent that the invention is  
7   generally applicable to eliminating the need for a photomask in optical lithography.

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9   **BRIEF DESCRIPTION OF THE DRAWINGS**

10          The above objects, features, and advantages of the present invention will become more  
11   apparent from the following detailed description taken with the accompanying drawings in  
12   which:

13          Figure 1 shows a first embodiment of the invention having a light source, a reflective  
14   spatial light modulator, such as a micro-mirror array, and a lens.

15          Figure 2 is a diagrammatic representation of a second embodiment of the invention  
16   employing an array of, for example, micro-lenses.

17          Figure 3 illustrates a micro-lens array in the form of Fresnel Zone Plates, which may  
18   be used in the invention.

19          Figure 4 shows a third embodiment of the invention having a transmissive spatial  
20   light modulator.

1 DESCRIPTION OF THE PREFERRED EMBODIMENTS

2 The present invention refers to articles and patents that contain useful supplementary  
3 information. These references are hereby incorporated by reference in their entireties.

4 The presently preferred invention is based on the principle that a Direct Write Optical  
5 Lithography System will significantly improve the cost, quality, and efficiency of polymer  
6 array synthesis by providing a maskless optical lithography system and method where  
7 predetermined image patterns can be dynamically changed during photolithographic  
8 processing. As such, an optical lithography system is provided to include a means for  
9 dynamically changing an intended image pattern without using a photomask. One such  
10 means includes a spatial light modulator that is electronically controlled by a computer to  
11 generate unique predetermined image patterns at each photolithographic step in polymer array  
12 synthesis. The spatial light modulators can be, for example, micromachined mechanical  
13 modulators or microelectronic devices (e.g. liquid crystal display (LCD)). The Direct Write  
14 System of the present invention using such spatial light modulators is particularly useful in  
15 the synthesis of polymer arrays, such as polypeptide, carbohydrate, and nucleic acid arrays.  
16 Nucleic acid arrays typically include polynucleotides or oligonucleotides attached to glass,  
17 for example, Deoxyribonucleic Acid (DNA) arrays.

18 Certain preferred embodiments of the invention involve use of the micromachined  
19 mechanical modulators to direct the light to predetermined regions (i.e., known areas on a  
20 substrate predefined prior to photolithography processing) of the substrate on which the  
21 polymers are being synthesized. The predetermined regions of the substrate associated with,  
22 for example, one segment (referred to herein as a pixel) of a micromachined mechanical  
23 modulator (e.g., a micro-mirror array) are referred to herein as features. In each

1 predetermined region or feature a particular oligonucleotide sequence, for example, is  
2 synthesized. The mechanical modulators come in a variety of types, two of which will be  
3 discussed in some detail below.

4 One type of mechanical modulator is a micro-mirror array which uses small metal  
5 mirrors to selectively reflect a light beam to particular individual features; thus causing the  
6 individual features to selectively receive light from a light source (i.e., turning light on and  
7 off of the individual features). An example is the programmable micro-mirror array Digital  
8 Micromirror Device (DMD™) manufactured by Texas Instruments, Inc., Dallas, Texas, USA.  
9 Texas Instruments markets the arrays primarily for projection display applications (e.g., big-  
10 screen video) in which a highly magnified image of the array is projected onto a wall or  
11 screen. The present invention shows, however, that with appropriate optics and an  
12 appropriate light source, a programmable micro-mirror array can be used for  
13 photolithographic synthesis, and in particular for polymer array synthesis.

14 The Texas Instruments' DMD™ array consists of 640 x 480 mirrors (the VGA version)  
15 or 800 x 600 mirrors (the super VGA (SVGA) version). Devices with more mirrors are under  
16 development. Each mirror is 16  $\mu\text{m}$  x 16  $\mu\text{m}$  and there are 1- $\mu\text{m}$  gaps between mirrors. The  
17 array is designed to be illuminated 20 degrees off axis. Each mirror can be turned on (tilted  
18 10 degrees in one direction) or off (tilted 10 degrees in the other direction). A lens (on axis)  
19 images the array onto a target. When a micro-mirror is turned on, light reflected by the  
20 micro-mirror passes through the lens and the image of the micro-mirror appears bright. When  
21 a micro-mirror is turned off, light reflected by the micro-mirror misses the lens and the image  
22 of the micro-mirror appears dark. The array can be reconfigured by software (i.e., every  
23 micro-mirror in the array can be turned on or off as desired) in a fraction of a second.



1       An optical lithography system including a micro-mirror array 1 based spatial light  
2 modulator according to one embodiment of the invention is shown in FIG. 1. This  
3 embodiment includes a spatial light modulator made of a micro-mirror array 1, and arc lamp  
4 3, and a lens 2 to project a predetermined image pattern on a chip or wafer (containing many  
5 chips) 4. In operation, collimated, filtered and homogenized light 5 from the arc lamp 3 is  
6 selectively reflected as a light beam 6 according to dynamically turned on micro mirrors in  
7 the micro-mirror array 1 and transmitted through lens 2 on to chip or wafer 4 as reflected light  
8 beam 8. Reflected light from micro-mirrors that are turned off 7 is reflected in a direction  
9 away from the lens 2 so that these areas appear dark to the lens 2 and chip or wafer 4. Thus,  
10 the spatial light modulator, micro-mirror array 1, modulates the direction of reflected light (6  
11 and 7) so as to define a predetermined light image 8 projected onto the chip or wafer 4. The  
12 direction of the reflected light alters the light intensity transmitted from each pixel to each  
13 feature. In essence, the spatial light modulator operates as a directional and intensity  
14 modulator.

15       The micro-mirror array 1 can be provided by, for example, the micro-mirror array of  
16 the Texas Instruments(TI) DMD, in particular, the TI "SVGA DLP™" subsystem. The Texas  
17 Instruments "SVGA DLP™" subsystem with optics may be modified for use in the present  
18 invention. The Texas Instruments "SVGA DLP™" subsystem includes a micro-mirror array  
19 (shown as micro-mirror array 1 in Fig. 1), a light source, a color filter wheel, a projection  
20 lens, and electronics for driving the array and interfacing to a computer. The color filter  
21 wheel is replaced with a bandpass filter having, for example, a bandpass wavelength of 365-  
22 410 nm (wavelength dependent upon the type of photochemicals selected for used in the  
23 process). For additional brightness at wavelengths of, for example, 400-410 nm, the light

1 source can be replaced with arc lamp 3 and appropriate homogenizing and collimating optics.

2 The lens included with the device is intended for use at very large conjugate ratios and is  
3 replaced with lens 2 or set of lenses appropriate for imaging the micro-mirror array 1 onto  
4 chip or wafer 4 with the desired magnification. Selection of the appropriate lens and  
5 bandpass filter is dependent on, among other things, the requisite image size to be formed on  
6 the chip, the type of spatial light modulator, the type of light source, and the type of  
7 photoresist and photochemicals being used in the system and process.

8 A symmetric lens system (e.g., lenses arranged by type A-B-C-C-B-A) used at 1:1  
9 magnification (object size is the same as the image size) is desirable because certain  
10 aberrations (distortion, lateral color, coma) are minimized by symmetry. Further, a  
11 symmetric lens system results in a relatively simple lens design because there are only half as  
12 many variables as in an asymmetric system having the same number of surfaces. However, at  
13 1:1 magnification the likely maximum possible chip size is 10.88 mm x 8.16 mm with a VGA  
14 device, or 10.2 mm x 13.6 mm with an SVGA device. Synthesis of, for example, a standard  
15 GeneChip® 12.8 mm x 12.8 mm chip uses an asymmetric optical system (e.g., a  
16 magnification of about 1.25:1 with SVGA device) or a larger micro-mirror array (e.g.,  
17 1028 x 768 mirrors) if the mirror size is constant. In essence, the lens magnification can be  
18 greater than or less than 1 depending on the desired size of the chip.

19 In certain applications of the invention, a relatively simple lens system, such as a  
20 back-to-back pair of achromats or camera lens, is adequate. A particularly useful lens for  
21 some applications of the invention is the Rodenstock (Rockford, IL) Apo-Rodagon D. This  
22 lens is optimized for 1:1 imaging and gives good performance at magnifications up to about  
23 1.3:1. Similar lenses may be available from other manufacturers. With such lenses, either

1 the Airy disk diameter or the blur circle diameter will be rather large (maybe 10  $\mu\text{m}$  or  
2 larger). See *Modern Optical Engineering*, 2d Edition, Smith, W.J., ed., McGraw-Hill, Inc.,  
3 New York (1990). For higher-quality synthesis, the feature size is several times larger than  
4 the Airy disk or blur circle. Therefore, a custom-made lens with resolution of about 1-2  $\mu\text{m}$   
5 over a 12.8 mm x 12.8 mm field is particularly desirable.

6 A preferred embodiment of synthesizing polymer arrays with a programmable micro-  
7 mirror array using the DMT process with photoresist takes place as follows. First, a  
8 computer file is generated and specifies, for each photolithography step, which mirrors in the  
9 micro-mirror array 1 need to be on and which need to be off to generate a particular  
10 predetermined image pattern. Next, the individual chip or the wafer from which it is made 4  
11 is coated with photoresist on the synthesis surface and is mounted in a holder or flow cell (not  
12 shown) on the photolithography apparatus so that the synthesis surface is in the plane where  
13 the image of the micro-mirror array 1 will be formed. The photoresist may be either positive  
14 or negative thus allowing deprotection at locations exposed to the light or deprotection at  
15 locations not exposed to the light, respectively (example photoresists include: negative tone  
16 SU-8 epoxy resin (Shell Chemical) and those shown in the above cited patents and U.S.  
17 patent appl. no. 08/634,053). A mechanism for aligning and focusing the chip or wafer is  
18 provided, such as a x-y translation stage. Then, the micro-mirror array 1 is programmed for  
19 the appropriate configuration according to the desired predetermined image pattern, a shutter  
20 in the arc lamp 3 is opened, the chip or wafer 4 is illuminated for the desired amount of time, ~~and~~  
21 and the shutter is closed. If a wafer (rather than a chip) is being synthesized; a stepping-  
22 motor-driven translation stage moves the wafer by a distance equal to the desired center-to-

1 center distance between chips and the shutter of the arc lamp 3 is opened and closed again,  
2 these two steps being repeated until each chip of the wafer has been exposed.

3 Next, the photoresist is developed and etched. Exposure of the wafer 4 to acid then  
4 cleaves the DMT protecting groups from regions of the wafer where the photoresist has been  
5 removed. The remaining photoresist is then stripped. Then DMT-protected nucleotides  
6 containing the desired base (adenine (A), cytosine (C), guanine (G), or thymine (T)) are  
7 coupled to the deprotected oligonucleotides.

8 Subsequently, the chip or wafer 4 is re-coated with photoresist. The steps from  
9 mounting the photoresist coated chip or wafer 4 in a holder through re-coating the chip or  
10 wafer 4 with photoresist are repeated until the polymer array synthesis is complete.

11 It is worth noting that if a DPD method, using for example 1-(6-nitro-1,3-  
12 benzodioxol-5-yl)ethyloxycarbonyl (MeNPOC) chemistry, or a PAG method, using a  
13 polymer film containing a photoacid generator (PAG), are used for polymer array synthesis  
14 then photoresist would not be used and the process is somewhat simplified. However, the use  
15 of a direct write optical lithography system with a spatial light modulator is also applicable to  
16 performing a process of deprotection of reaction sites using the DPD and PAG methods  
17 without photoresist.

18 As is clear from the above described method for polymer array synthesis, no  
19 photomasks are needed. This simplifies the process by eliminating processing time  
20 associated with changing masks in the optical lithography system and reduces the  
21 manufacturing cost for polymer array synthesis by eliminating the cost of the masks as well  
22 as processing defects associated with using masks. In addition, the process has improved  
23 flexibility because reprogramming the optical lithography system to produce a different

1 generate and verify new photomasks, thus making it possible to transfer an image pattern  
2 computer file directly from a CAD or similar system to the optical lithography system or  
3 providing electronic signals directly from the CAD system to drive the optical lithography  
4 system's means for dynamically producing the desired light pattern (e.g., spatial light  
5 modulator). Therefore, the optical lithography system is simplified and more efficient than  
6 conventional photomask based optical lithography systems. This is particularly valuable in  
7 complex multiple step photolithography processing; for example polymer array synthesis of  
8 GeneChip® probe arrays having upwards of seventy or more cycles, especially when many  
9 different products are made and revised.

10 As indicated above, substrates coated with photoresist are employed in preferred  
11 embodiments of the invention, e.g., using the DMT process with photoresist. The use of  
12 photoresist with photolithographic methods for fabricating polymer arrays is discussed in  
13 McGall et al., *Chemtech*, pp. 22-32 (February 1997); McGall et al., *Proc. Natl. Acad. Sci.*,  
14 *U.S.A.*, Vol. 93, pp. 13555-13560 (Nov. 1996) and various patents cited above, all of which  
15 are incorporated by reference in their entireties. Alternatively, polymer array synthesis  
16 processing can be performed using photoacid generators without using a conventional  
17 photoresist, e.g., using the PAG process, or using direct photodeprotection without using any  
18 photoresist, e.g., using the DPD process. The use of photoacid generators is taught in U.S.  
19 Application No. 08/969,227, filed November 13, 1997. However, the present invention is  
20 particularly useful when using the DMT and PAG processes for polymer array synthesis. #

21 When synthesizing nucleic acid arrays, the photochemical processes used to fabricate  
22 the arrays is preferably activated with light having a wavelength greater than 365 nm to avoid  
23 photochemical degradation of the polynucleotides used to create the polymer arrays. Other

1 wavelengths may be desirable for other probes. Many photoacid generators (PAGs) based on  
2 *o*-nitrobenzyl chemistry are useful at 365 nm. Further, when using the mirror array from  
3 Texas Instruments discussed above, the PAG is preferably sensitive above 400 nm to avoid  
4 damage to the mirror array. To achieve this, *p*-nitrobenzyl esters can be used in conjunction  
5 with a photosensitizer. For example, *p*-nitrobenzyltosylate and 2-ethyl-9,10-dimethoxy-  
6 anthracene can be used to photochemically generate toluenesulfonic acid at 405 nm. See S.C.  
7 Busman and J.E. Trend, *J. Imag. Technol.*, 1985, 11, 191; A. Nishida, T. Hamada, and  
8 O. Yonemitsu, *J. Org. Chem.*, 1988, 53, 3386. In this system, the sensitizer absorbs the light  
9 and then transfers the energy to the *p*-nitrobenzyltosylate, causing dissociation and the  
10 subsequent release of toluensulfonic acid. Alternate sensitizers, such as pyrene, *N,N*-  
11 dimethylnaphthylamine, perylene, phenothiazine, canthone, thiocanthone, actophenone, and  
12 benzophenone that absorb light at other wavelengths are also useful.

13 A variety of photoresists sensitive to 436-nm light are available for use in polymer  
14 array synthesis and will avoid photochemical degradation of the polynucleotides.

15 A second preferred mechanical modulator that may be used in the invention is the  
16 Grating Light Valve™ (GLV™) available from Silicon LightMachines, Sunnyvale, CA, USA.  
17 The GLV™ relies on micromachined pixels that can be programmed to be either reflective or  
18 diffractive (Grating Light Valve™ technology). Information regarding certain of the  
19 mechanical modulators discussed herein is obtained at <http://www.ti.com> (Texas instruments)  
20 and <http://siliconlight.com>. (Silicon LightMachines).

21 Although preferred spatial light modulators include the mechanical modulators  
22 DMD™ available from Texas Instruments and the GLV™ available from Silicon  
23 LightMachines, various types of spatial light modulators exist and may be used in the practice

1 of the present invention. See *Electronic Engineers 'Handbook*, 3<sup>rd</sup> Ed., Fink, D.G. and  
2 Christiansen, D. Eds., McGraw-Hill Book Co., New York (1989). Deformable membrane  
3 mirror arrays are available from Optron Systems Inc. (Bedford, MA). Liquid-crystal spatial  
4 light modulators are available from Hamamatsu (Bridgewater, NJ), Spatialight (Novato, CA),  
5 and other companies. However, one skilled in the art must be careful to select the proper  
6 light source and processing chemistries to ensure that the liquid-crystal spatial light  
7 modulator is not damaged since these devices may be susceptible to damage by various  
8 ultraviolet (UV) light. Liquid-crystal displays (LCD; e.g., in calculators and notebook  
9 computers) are also spatial light modulators useful for photolithography particularly to  
10 synthesize large features. However, reduction optics would be required to synthesize smaller  
11 features using LCDs.

12       Some spatial light modulators may be better suited than the Texas Instruments device  
13 for use with UV light and would therefore be compatible with a wider range of photoresist  
14 chemistries. One skilled in the art will choose the spatial modulator that is compatible with  
15 the chosen wavelength of illumination and synthesis chemistries employed. For example, the  
16 device from Texas Instruments DMD™ should not be used with UV illumination because its  
17 micro-mirror array may be damaged by UV light. However, if the passivation layer of the  
18 micro-mirror array is modified or removed, the Texas Instruments DMD™ could be used in  
19 the invention with UV light.

20       One embodiment that is particularly useful when extremely high resolution is required  
21 involves imaging the micro-mirror array using a system of the type shown in Fig. 2. In this  
22 system, a lens 12 images the micro-mirror array 11 (e.g., DMD™ or GLV™) onto an array 10  
23 having an array of micro-lenses 15 or non-imaging light concentrators. Each element of the

1 array 10 focuses light onto the chip or wafer, e.g., Gene Chip array 14. Each micro-lens 15  
2 produces an image of one pixel of the micro-mirror array 11. Optics 16, including a shaping  
3 lens 17 may be included to translate light from a light source 13 onto the micro-mirror array  
4 11.

5 For example, if an SVGA DLP™ device is imaged with 1:1 magnification onto a  
6 micro-lens array 10, an appropriate micro-lens array 10 can consist of 800 x 600 lenses  
7 (micro-lenses 15) with 17  $\mu\text{m}$  center-to-center spacing. Alternatively, the micro-lens array  
8 can consist of 400 x 300 17  $\mu\text{m}$  diameter lenses with 34  $\mu\text{m}$  center-to-center spacing, and  
9 with opaque material (e.g., chrome) between micro-lenses 15. One advantage of this  
10 alternative is that cross-talk between pixels is reduced. The light incident upon each micro-  
11 lens 15 can be focused to a spot size of 1-2  $\mu\text{m}$ . Because the spot size is much less than the  
12 spacing between micro-lenses, a 2-axis translation stage (having, in these examples, a range  
13 of travel of at least either 17  $\mu\text{m}$  x 17  $\mu\text{m}$  or 34  $\mu\text{m}$  x 34  $\mu\text{m}$ ) is necessary if complete  
14 coverage of the chip or wafer 14 is desired.

15 Micro-lenses 15 can be diffractive, refractive, or hybrid (diffractive and refractive).  
16 Refractive micro-lenses can be conventional or gradient-index. A portion of a diffractive  
17 micro-lens array 10 is shown in Figure 3 and has individual micro-lenses formed as circles  
18 commonly known as Fresnel Zone Plates 20. Alternatively an array of non-imaging light  
19 concentrators can be employed. An example of such an approach would include a short piece  
20 of optical fiber which may be tapered to a small tip.

21 Furthermore, some spatial light modulators are designed to modulate transmitted  
22 rather than reflected light. An example of a transmissive spatial light modulator is a liquid



1 crystal display (LCD) and is illustrated in another embodiment, shown in Fig. 4. This  
2 embodiment includes a light source 33 providing light 35, transmissive spatial light  
3 modulator 31 and a computer 39 providing electronic control signals to the transmissive  
4 spatial light modulator 31 through cables 40 so as to transmit a desired light image 38 on the  
5 chip or wafer 34. The computer 39 may be, for example, a unique programmable controller,  
6 a personal computer (PC), or a CAD system used to design the desired image pattern.

7 Using a transmissive spatial light modulator has even additional advantages over the  
8 conventional optical lithography system. Reflective spatial light modulators require a large  
9 working distance between the modulator and the lens so that the lens does not block the  
10 incident light. Designing a high performance lens with a large working distance is more  
11 difficult than designing a lens of equivalent performance with no constraints on the working  
12 distance. With a transmissive spatial light modulator the working distance does not have to  
13 be long and lens design is therefore easier. In fact, as show in Fig. 4, some transmissive  
14 spatial light modulators 31 might be useful for proximity or contact printing with no lens at  
15 all, by locating the modulator very close to the chip or wafer 34.

16 In fact, the transmissive spatial light modulator in the embodiment of Fig. 4 could be  
17 replaced by an LED array or a semiconductor laser arrays emitting light of the appropriate  
18 wavelength, each of which not only may be operated to dynamically define a desired image  
19 but also act as the light source. Thus, as modified, this embodiment would be simplified so  
20 as to not require a separate light source.

21 Although discussed herein in reference to polymer array synthesis, one skilled in the  
22 art will appreciate that the present invention has a variety of applications including, among  
23 others, silicon micromachining and custom semiconductor chip manufacturing. However,

1 use of some types of spatial light modulators with the invention may result in limiting the  
2 types of geometries available in silicon micromachining and custom semiconductor chip  
3 manufacturing applications. It is understood that the examples and embodiments described  
4 herein are for illustrative purposes only and that various modifications or changes in light  
5 thereof will be suggested to persons skilled in the art and are to be included within the spirit  
6 and purview of this application and scope of the appended claims.

7 All publications, patents, and patent applications cited herein are hereby incorporated  
8 by reference in their entirety for all purposes. Application Serial No. 08/426,202 (filed April  
9 21, 1995) relates to the present invention and is hereby incorporated by reference for all  
10 purposes.